

Docket No. 003239.P065  
Express Mail No. EL466330391US

UNITED STATES PATENT APPLICATION

FOR

WIRELESS LAN WEP INITIALIZATION  
VECTOR PARTITIONING SCHEME

Inventors:

DARWIN A. ENGWER

JONATHAN M. ZWEIG

Prepared by:

Blakely, Sokoloff, Taylor & Zafman LLP  
12400 Wilshire Boulevard, Suite 700  
Los Angeles, California 90025  
(714) 557-3800

**WIRELESS LAN WEP INITIALIZATION  
VECTOR PARTITIONING SCHEME**

This application claims benefit of U.S. Provisional Application No. 60/226,404, filed August 18, 2000.

**5 FIELD OF THE INVENTION**

The present invention relates to the field of networking. In particular, this invention relates to a technique for providing enhanced security for transmissions over a wireless local area network.

**BACKGROUND OF THE INVENTION**

10 The ability of users to access programs and share data over local area networks (referred to as "LANs") has become a necessity for most working environments. To improve efficiency and ease of use, certain enhancements may be added to a LAN such as remote wireless access. By providing remote wireless access, a wireless LAN (WLAN) is formed.

15 As described in U.S. Patent No. 5,987,062 issued to Netwave Technologies, Inc., now owned by Nortel Networks Limited, one type of WLAN employs dedicated stations, which are referred to as access points (APs). Therein, each AP is a relay station that includes a radio frequency (RF) transceiver that receives radio data packets over a communication channel from mobile units. Of course, each AP also transmits  
20 radio data packets over the communication channel to the mobile units.

To discourage an interloper from eavesdropping on communications between an AP and a mobile unit, a data confidentiality algorithm may be utilized within a WLAN. In accordance with Institute of Electrical and Electronics Engineers (IEEE) 802.11, this data confidentiality algorithm is referred to as "wired equivalent privacy" (WEP). In  
25 general, WEP is a symmetric key algorithm that is configured to encrypt information with a combination of a secret key and an initialization vector (described below) prior to transmission over a wireless link. This prevents an interloper from obtaining an unauthorized, non-encrypted copy of data communicated between an AP and its mobile units.

30 As shown in Figure 1, a block diagram of a WEP shared key authentication sequence is shown. In general, a mobile unit 10 issues an authentication request 100 to

an access point (AP) 20. In response, the AP 20 returns a challenge text 110. Herein, the “challenge text” 110 is a sequence of alphanumeric characters approximately 128 bytes in size and generated by the AP 20. Upon receipt, the challenge text 110 is encrypted using a secret key 120 that was previously negotiated by the mobile unit 10 and the AP 20, concatenated with a series of bits of a predetermined number, referred to as an “initialization vector” (IV) 130. The IV 130 is concatenated with the encrypted challenge text and transmitted. This produces a “challenge response” 140, which is sent to the AP 20.

Upon receiving the challenge response 140, if the AP 20 is able to recover the challenge text 110 using its own stored version of the secret key 120, the mobile unit 10 is authenticated. Otherwise, the mobile unit 10 is not authenticated and the AP 20 will not receive and process its transmitted data.

Although WEP provides greater security to communications between the AP and its mobile units, the content of these communications is still subject to attack. For example, an interloper can monitor authentication sequences between the mobile units and an AP. As shown, from the authentication sequence, an interloper can obtain an IV and a portion (approximately 128 bytes) of the keying material (based on the secret key and initialization vector) by performing an exclusive-or (XOR) operation on both the encrypted challenge text and the challenge text 110. By maintaining a record of the IVs and their portion of keying material, an interloper can decrypt an amount of encrypted information without knowledge of the secret key.

#### SUMMARY OF THE INVENTION

The invention relates to partitioning of the initialization vectors (IVs). Certain IVs are reserved for use in connection with the WEP authentication sequence while the remaining IVs are reserved for encrypting and decrypting communications not involving authentication. This mitigates the likelihood of a successful attack on transmissions over a wireless local area network by an eavesdropper using key sequences recovered from an authentication event to decrypt data. Optionally, this prevents replay attacks from being used..

Other aspects and features of the present invention will become apparent to those ordinarily skilled in the art upon review of the following description of specific embodiments of the invention in conjunction with the accompanying claims and figures.

### BRIEF DESCRIPTION OF THE DRAWINGS

The features and advantages of the present invention will become apparent from the following detailed description of the present invention in which:

5 Figure 1 is a block diagram of a conventional WEP authentication sequence with an interloper extracting pertinent information.

Figure 2 is a first exemplary embodiment of a wireless network system.

Figure 3 is an exemplary embodiment of an access point (AP) for a wireless network system.

10 Figure 4 is a first exemplary embodiment of a WEP authentication sequence for the present invention.

Figure 5 is a second exemplary embodiment of a WEP authentication sequence for the present invention.

Figure 6 is an exemplary embodiment of a WEP encryption sequence for the present invention.

15 Figure 7 is an exemplary embodiment of a WEP decryption sequence for the present invention.

Figure 8 is a second exemplary embodiment of a wireless network system utilizing WEP encryption and decryption sequences of Figures 4-7.

U.S. GOVERNMENT USE

## DETAILED DESCRIPTION OF THE INVENTION

Herein, the exemplary embodiments of the present invention relate to a technique for enhancing the level of security provided by a wired equivalent privacy (WEP) protocol for information transmitted over a wireless local area network. This 5 enhanced security is provided through initialization vector (IV) partitioning. In particular, only certain IVs may be used for WEP authentication while other IVs may be used for communications not involving authentication (hereinafter referred to as “data communications”). These embodiments are not exclusive; rather, they merely provide a thorough understanding of the present invention. Well-known circuits are not 10 set forth in detail in order to avoid unnecessarily obscuring the present invention.

In the following description, certain terminology is used to describe features of the present invention. For example, “logic” includes hardware and/or software module(s) that perform a certain function on incoming information. A “software module” is executable code such as an operating system, an application or an applet for 15 example. The term “information” is defined as data, address, and/or control. For transmission, the information may be placed in a frame featuring a single data packet or a series of data packets. A “link” is broadly defined as one or more information-carrying mediums to establish a communication pathway. Examples of the medium include a physical medium (e.g., electrical wire, optical fiber, cable, bus traces, etc.) or 20 a wireless medium (e.g., air in combination with wireless signaling technology).

With respect to cryptographic functionality, a “hash function” is a program or a collective process for converting information into a value represented by a fixed bit length. Normally, hash functions are “one-way” so that there does not readily exist an inverse function to recover a portion of the original information from the hash value. 25 Examples of a standard hash function include Secure Hash Algorithm (SHA-1) as specified by the National Institute of Standards and Technology located in Washington, D.C. The term “combined” is generally defined that an arithmetic operation such as concatenation, modular addition, hashing, or another mathematical operation.

Referring to Figure 2, a first exemplary embodiment of a wireless network 30 system 200 in accordance with the invention is illustrated. The wireless network system 200 comprises a link 201 based on a physical medium. Herein, the link 201 is part of a wired backbone network 202 that includes network resources 204 available for users of the system 200. The wireless network system 200 further includes one or more

access points (APs) 206a-206d that communicate via a wireless link with one or more wireless units (WUs) 208a-208f. For this embodiment, four (4) APs 206a-206d communicate with four (4) WU 208a-208f.

Users using the WUs 208a-208f can access the network resources 204 via any 5 of the APs 206a-206d, which are generally transparent bridges that link a wireless network defined by one or more WUs 208a-208f with the wired backbone network 202. The WUs 208a-208f communicate with the APs 206a-206d typically using a standardized protocol, such as the IEEE 802.11 protocol.

A “wireless unit” (WU) is defined herein as any electronic device comprising 10 processing logic (e.g., a processor, microcontroller, state machine, etc.) and a wireless transceiver for receiving and transmitting data to an access point (AP) or another wireless unit (WU). Examples of a WU include a computer (e.g., desktop computer, laptop computer, hand-held computer such as a personal digital assistant “PDA”, etc.), communications equipment (e.g., pagers, telephones, facsimile machine, etc.), a 15 television set-top box, or appliances such as refrigerator pads, electronic picture frames, alarm detectors, water detectors, and the like.

An “access point” (AP) is a device that provides a bi-directional connection between one or more WUs and a network such as the wired backbone network 202. However, an AP could also have a wireless connection back to the backbone network 20 202, such as AP 206d, which has a wireless link to the backbone network 202 via another AP 206c. The wired backbone network 202 can be of any type, including an Ethernet, a token ring, and an asynchronous transfer mode (ATM) network.

Referring now to Figure 3, an exemplary embodiment of an access point (AP) is shown. For illustrative purposes, the access point is represented by AP 206b and 25 differs in function from the access points described in U.S. Patent No. 5,987,062. As shown, AP 206b comprises logic 300 and 302, an address table 304 and one or more keys 305, a device management logic 306, a wireless transceiver interface 308, a number generator 310 and an optional “used IV” database 311 to maintain a listing of IVs already used for authentication. In particular, the logic 300 is used to determine 30 whether certain information from the wired backbone network 202 is destined for one or more of the WUs. The address table 304 includes Medium Access Control (MAC) addresses for all of the wireless units associated with the AP 206b such as WUs 208c and 208d of Figure 2. In the special case of all broadcast or some multicast packets, the

packets are addressed to all or some of the wireless units (WUs) associated with the access point (AP) on a “best effort” basis.

Similarly, as information from the wireless units (WU) is received by the wireless transceiver 308, the logic 302 monitors addresses within this information against the contents of the address table 304. One reason is that only information from authenticated and associated wireless units (e.g., WUs 208c and 208d) is accepted. Hence, if a non-authenticated wireless unit transmits packets, these packets will not be forwarded to the wired backbone network 202 of Figure 1. The logic 302 subsequently transmits the information to the logic 300 for routing to the wired backbone network

10 202.

In the event that the fixed backbone network 202 of Figure 1 has a substantially larger data rate than the wireless network, content addressable memory (CAM) 312 and a hardware address filter (HAF) 314 may be employed within the AP 206b. The CAM 312 and HAF 314 are in communication with the fixed backbone network 202 and 15 collectively filter information at the hardware level so that the logic 300 processes only a small portion of the information routed over the wired backbone network 202.

The device management logic 306 provides a mechanism for adjusting the various parameters and controlling the functionality of the AP 206b. An example of one mechanism involves placement of an interface (e.g., serial) port 316 within the AP 206b. The interface 316 provides a direct connection to the AP 206b. Other mechanisms include (1) Simple Network Management Protocol (SNMP) management tools such as OPTIVITY® by Nortel Networks Limited of Montreal, Canada, (2) TELNET, or (3) web-based management software.

As shown, for this embodiment, the number generator 310 is employed within the AP 206b. Of course, it is contemplated that the number generator 310 may be employed in a wireless unit (WU) as well. In one embodiment, number generator 310 is a software-based pseudo-random number generator that produces a pseudo-random bit stream, which is utilized as an initialization vector (IV) as described in Figure 4. An example of the pseudo-random number generator includes RC4, a software module 30 produced by RSA Data Security, Inc. of Redwood City, California. In another embodiment, number generator 310 is a hardware-based random number generator that produces random bit patterns.

Referring back to Figure 2, in the typical scenario, a WU associates itself with one of the APs to communicate with the wired backbone network 202. For instance, in

the example shown in Figure 2, WUs 208a and 208b are associated with AP 206a, WUs 208c and 208d are associated with AP 206b, WU 208e is associated with AP 206c, and WU 208f is associated with wireless AP 206d. Which access point (AP) a wireless unit (WU) is associated with can depend on many factors, including signal quality, load  
5 balancing, restricted links and other factors. The AP that a particular WU is associated with can change, such as when the WU “roams” from the coverage area of a particular AP to a coverage area of another AP. From the standpoint of the user using the WU, this change in associated AP is transparent. The WU must authenticate itself prior to this association.

10 Referring now to Figure 4, a first exemplary embodiment of a WEP authentication sequence for the present invention is shown. Herein, a wireless unit (e.g., wireless unit 208c) issues an authentication request 400 to an access point “AP” (e.g., 206b). In response, the AP 206b generates a first sequence of bits that are referred to as a “challenge text” 410. Upon receipt of the challenge text 410, the  
15 wireless unit 208c generates a second sequence of bits referred to as an “initialization vector” (IV) 420.

Being 24-bits in length, the IV 420 is analyzed by the WU 208c in order to determine whether the IV 420 falls within a first group referred to as a first partitioned region (FPR) 425. If the IV 420 is determined to fall within the first partitioned region  
20 425, the IV 420 is subsequently used in the authentication sequence. Otherwise, a new IV 420 is generated and analyzed until an IV in the first partition region 425 is generated. The “first partitioned region” 425 comprises a group of IV bit patterns that are solely used in connection with the authentication sequence. In one embodiment, the determination of whether the IV 420 falls within the first partitioned region 425 is  
25 accomplished by determining whether distinct field of bits have been set and/or cleared. For example, for an authentication sequence, the IV 420 may require that its four (4) most significant bits are set before transmitting the IV 420 as part of a return message to the AP 206b. Another example is that a select number of bits, either continuous or discontinuous are set. Yet another example would be to have the first partition region  
30 425 be all numeric values within a certain range.

If the IV 420 falls within the first partitioned region 425, the challenge text 410 is encrypted based on the IV 420, combined with the shared secret key (SK) 430 that was previously negotiated by the wireless unit 208c and the AP 206b as described below in Figure 6. The encrypted challenge text 410 and the IV 420 form a “challenge

response” 440, which is sent to the AP 206b. If the AP 206b is able to recover the challenge text 410 using its pre-stored SK 430 and the IV 420, the wireless unit 208c is authenticated. Otherwise, the wireless unit 208c is not authenticated and the AP 206b will not receive and process information transmitted by the wireless unit 208c. If the 5 AP 206b is maintaining the used IV database 311 and the IV 420 is contained within the database 311, then the wireless unit is not authenticated.

Referring now to Figure 5, a block diagram of a second exemplary embodiment for a WEP authentication sequence of the present invention is shown. Herein, a wireless unit (e.g., wireless unit 208c) issues an authentication request 500 to an access point “AP” (e.g., AP 206b). In response, the AP 206b generates a first sequence of bits (referred to as a “challenge text” 510) and a second sequence of bits referred to as the “initialization vector” (IV) 520. Herein, the AP 206b analyzes the IV 520 in order to verify that the IV 520 falls within the first partitioned region as described above. If not, the IV 520 is regenerated and analyzed. Optionally, the AP 206b can maintain a listing 10 (database) 311 of IVs used for authentication to ensure that the IV 520 has not been generated before or communicate with other APs to verify that they have not previously 15 used the proposed IV 520.

If the IV 520 falls within the first partitioned region, the challenge text 510 and the IV 520 are transferred to the WU 208c. The WU 208c encrypts the received 20 challenge text 510 using a combination of the IV 520 and the shared secret key (SK) 430 that was previously negotiated by the wireless unit 208c and the AP 206b as described below in Figure 6. This produces a “challenge response” 540, which is sent to the AP 206b for authentication purposes. This allows the AP 206b to control the partitioning between IVs used for authentication and IVs used for encrypting data 25 frames. Also, this provides a mechanism for protecting against replay attacks. A response 540 that contains a different IV is discarded.

Referring now to Figure 6, an exemplary embodiment of a WEP encryption sequence is shown. Initially, an initialization vector (IV) 600 is produced by a first device (e.g., AP or WU) that is in communication with a second device (e.g., WU or 30 AP). The IV 600 is analyzed to determine whether it falls within the first partitioned region. If the IV 600 is produced during the authentication sequence, the IV 600 is regenerated and analyzed if it does not fall within the first partition region. Similarly, if the IV 600 is produced for WEP encrypting during data communications, the IV 600 is regenerated and analyzed if it falls within the first partition region.

Otherwise, the IV 600 is combined with the shared secret key (SK) 430 to produce a seed 610. The seed 610 is input into a number generator 310, which outputs a first key sequence 620. The “first key sequence” 620 is a pseudo-random sequence of bytes greater in length than the number of data bytes of information to be encrypted 5 (referred to as “plaintext” 630).

The plaintext 630 is combined with its integrity check value (ICV) 640 to produce a data sequence 650. The “ICV” 640 is a hash value of the plaintext 630 for use to verify the integrity of the plaintext 630 after transmission. The first key sequence 620 and the data sequence 650 undergo a logical operation (e.g., an exclusive-10 OR “XOR”) to encrypt the plaintext 630. The encrypted plaintext is referred to as “ciphertext” 660. The ciphertext 660 is included in a data frame 670 with a header information 671 and the IV 600.

Referring to Figure 7, an exemplary embodiment of a WEP decryption sequence is shown. The WEP decryption sequence commences with the arrival of the frame 670. 15 The IV 600 is recovered from the data frame 670 and combined with a secret key (e.g., same as SK 430) stored at the second device to produce a seed 700. For this example, the seed 700 is input into a number generator (e.g., pseudo-random number generator such as RC4), which outputs a second key sequence 710. The second key sequence 710 and the ciphertext 660 from the data frame 670 undergo a logical operation (e.g., 20 XOR) to recover the original plaintext 630 and the ICV 640. The integrity of the communications is checked by performing a hash operation on the recovered plaintext 630 to produce a check ICV (ICV’) 720. If the ICV 640 does not match ICV’ 720, an error in the communications has occurred. Thus, the plaintext 630 is not utilized. Otherwise, the plaintext 630 is used.

25 It is contemplated that alternative communication schemes may be used. For example, the secure communications may be established between multiple wireless units (WUs) as shown in Figure 8. In this embodiment, the wireless network system 800 comprises two or more wireless units (WU) that can communicate with each other via a wireless link. In this example, four WUs 802, 804, 806 and 808 are shown, each 30 of which can communicate with the remaining units via the wireless link. In contrast to the wireless network systems of Figures 1 and 3, this wireless network system 800 does not use a wired backbone network or APs. This type of system 800 is known in the relevant art as an “ad hoc” wireless network system. The WEP encryption sequence

and the WEP decryption sequence are performed between WUs in the same manner as described in Figures 6 and 7.

While certain exemplary embodiments have been described and shown in the accompanying drawings, it is to be understood that such embodiments are merely 5 illustrative of and not restrictive on the broad invention, and that this invention not be limited to the specific constructions and arrangements shown and described, since various other modifications may occur to those ordinarily skilled in the art.